TNE80013 Software Managed Networks

Research Report - Portfolio Task

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Abstract: Cellular networks are networks that allow for movement between base stations to which provides connectivity. This greatly improved the mobile aspect of access the internet and networks. The network technology underlying this mobile access has had five generations ranging from 1G through to 5G with 6G upcoming. Each generation made major strides in different aspects, from 2Gs introduction of voice and messaging communications, 4Gs impact in digital economics and 5Gs influence in across many industries. 6G proposes lighting fast data rates and sub millisecond latency and revolutionary interconnected cities. This report will briefly view the history and comparison of cellular networks, examine the applicability of 6G and technologies it enables and provide a short analysis of 6Gs future relative to the gathered information.

I. Introduction

6G cellular (mobile) networks is a technology culmination of previous generations originating from 1G. Each evolution's development regards for the previous generations weakness and aims for not only improvement but innovation with current and future technologies. The increase in efficiency of computing power has made prominent advancements with the Internet of Things (IoT). With estimations ranging in the tens of billions [1], the underlying technology is needed to support the growth. Research and development are required in the physical layer (wave modulation techniques), bandwidth, efficiency and latency [2][3][4].

Through the 2030s is the given estimate for the introduction of 6G. The completion of this endeavour shall propel society to further interconnect current and future systems, with capabilities of one-million connections per square kilometre [3]. Other defining capabilities: Highly capable holographic media, enhanced virtual reality, ultra-low latency for tactile communication and systems requiring precisely timed data [2][3]. Another expansive field is Artificial Intelligence and Machine Learning (AI/ML), 6G looks to integrate is capabilities for optimization in areas such as the physical layer or large networks. All refinements or introductions for 6G also must cover concerns for cyber security [4], particularly Quantum Resistant Cryptography (QRC) [5].

The following in this report will briefly describe the history of previous evolutions of cellular networks and furthermore a comparison of each iteration, starting from 2G. Then finally describe further in-detail 6G and its implications in future networks and communications. Additionally, a section dedicated to viewing 6G from a Software Defined Networking (SDN) perspective. Finally, a conclusive statement regarding 6G and its prospective future.

II. Evolution of Mobile Generations

Cellular (or mobile) networks are referred to as such because of the region of connectivity surrounding a base station transceiver. It is referred to as a "cell", the user can transition from cell to cell maintaining connectivity allowing a mobile connection, therefore a cellular or mobile network. Note: The following covers the evolution of each generation and not the in-between improvements e.g. 2.5G.

2G - Second Generation

Second generation (1990s) transitioned from analogue to digital signal and allowed for voice transmission (64 kbps) but also introduce Short Message Service (SMS) [6]. Second generation could allow more users to be connected utilising GSM or CDMA [7].

3G - Third Generation

Third generation (2000s) introduced a global standard for 3G networks under the IMT-2000 standardization [7], it also handled information regarding ensuring smooth transition from second generation networks. Third generation introduced access to television, global roaming, operations at a bandwidth of 15-20Mhz, video calls and higher speed to internet access [6][7].

4G - Fourth Generation

Fourth generation (2010s) is still widely used and will likely see into 2030s given 3G was only recently disabled in late 2024 in Australia. Fourth generation introduction brought upon due to increasing growth demand from users [6]. It required higher QoS along with increases of data rate and reductions in latency. This enabled service alike to a home network fully offering its capabilities as 4G mobile broadband. Furthermore, it pushed the capabilities of mobile devices to essentially being handheld computers. Availability enabling features included the concept of high-capacity areas as hot zones and therefore higher data rates requirements for specific zones [8]. Further advances in other technologies such as various media content like video streaming and broadcasting, TV all through fourth generation mobile broadband [7].

5G - Fifth Generation

Fifth Generation (2020s) early prospective claims have unfortunately fell short, claims of smart cities integrated with IoT impacting positively for areas such as transport, energy, healthcare and manufacturing [9]. Utilising Fifth Generations improved high-data rate, lower latency and high-connection density to enable advancements in said areas. However, the deployment of Fifth Generation has been limited and that 80% of users globally will have 5G coverage in 2028 [9]. Considering Australia's isolated distances from major cities that major portions of the population live, regional areas may take longer. The drop out range of 5G is significant even when leaving Melbourne and the underlying infrastructure supporting Fifth Generation is 4G technology. The technological improvements made to cellular networks by Fifth Generation are in hand but the support at which it needs to operate at full capacity is underhanded [9].

6G - Sixth Generation

Sixth Generation (2030s) looks to further improve data speeds and lower latency to fully support IoT being integrated into the world. Impacts are to be made socially, in infrastructure, industrial purposes, health sector and more with integration with the prosperous future of AI/ML.

III. Comparison of Wireless Generations

Generation	Data rate	Latency	Core Architecture	Use Cases	Limitations
2G	64 Kbps	300ms	Circuit-switched digital voice	Voice calls and SMS	Low data rate with limited technology
3G	2 Mbps	100ms	Combination of circuit + packet switching	Mobile internet, video calling, mobile apps	Congestion, cost, scalability
4G	100 Mbps - 1 Gbps	30-50ms	All-IP packet switched (LTE)	Fast data speeds enabling quick internet service, cloud services	Density issues regarding connections, high spectrum cost
5G	~ 20 Gbps	10ms	Software defined, cloud-based principles, network slicing	IoT integration benefitting social and industrial aspects,	Infrastructure costs, limited coverage relative to cost
6G	~ 1 Tbps	1ms	AI-native, THz spectrum, integrated space-air-ground networks	Further enhancement with IoT, integration with concurrently expanding technologies	Experimental phase, high energy demand, new infrastructure, security requirements

Table 1 Cellular network generation comparison

6G has potential the largest impact regarding fully integrated IoT devices interconnected changing infrastructure and all kinds of sectors from health to business. With its current projection's, it may become the largest leap in terms of cellular networks and the digital world. However, it shouldn't undermine the hurdles that each previous generation overcame to allow for current cellular networks. Each generation enabled better networks, in the older generations it was to accommodate social uses with voice calls and SMS. Until computing power was able to be reduced into a today's mobile smartphones size, where the internet is fully accessible at exceptional speed given coverage. With the latest 5G and proposed 6G, each are geared to fusing together digital and physical worlds. Despite Fifth Generation's suboptimal rollout across some regions, there are still aspects which can be viewed currently such as self-driving cars and haptic surgeries.

IV. 6G Benefits & Applications

The 6G boasts impressive peak data rates of 1 Tbps in combination with ultra-low latency, 6G aims to achieved higher capacity by a factor of 1000 relative to 5G through widely adopting terahertz frequency [10]. Terahertz frequencies are ideal in high-speed transmission with large bandwidth capabilities, it is not exempt from disruption due to various factors such as weather conditions, material penetration ability or range. In [10], authors provide a list of 6G requirements outlining the innovations that 6G development will need to incur to function at full capacity. Authors also included enabling technologies (applications) of 6G networks, a select summary of ten enabled technologies is as follows:

Internet of Things (IoT) - Interconnecting masses of devices supporting a fully integration of the physical and digital world wirelessly. The IoT devices include many types of devices, e.g. industrial sensors receiving data for that triggers automation service for energy-efficient systems.

Artificial intelligence (AI) - Growth of AI in all aspects of technology continues to grow and it does not exclude networks. 5G has partial integration with AI, where 6G is focused to bring full integration and introduced the benefits of automation and efficiency that AI brings.

Wireless Information and Energy Transfer (WIET) - The radio waves of transponders carry encoded information for data transfer. It may be capable of integrating wireless charging through WIET. The wave is subject to carry energy as well information and therefore beneficial for low-powered IoT devices.

Mobile edge computing (MEC) - Bringing the computing power closer to end devices is beneficial to 6G as it cuts the delay for travel to servers further reducing latency. This would mean that heavier software like AI models can be run locally further improving efficiency for resolving real-time calculations.

Integration of sensing and communication - Systems of 6G shall be able to process their physical surrounding information through sensors and make decisions relative to the information gathered.

Holographic beamforming - A method of which the direction of radio signals can be precisely targeted diminishing potential interference and improvements in transmission efficiency.

Big data analytics - Large complex datasets will be retrieved from IoT sensors or any other form of data collection. Handling dataset efficiently with accurate calculations results in 6G networks providing self-optimizations to the network itself, or any other analysis use case predicating of big data.

Unmanned Aerial Vehicles (UAV) - Drones usage is increasing in commercial and military market. Enhanced connectivity for UAVs will upgrade display imaging and the drone itself can be used as a mobile base station.

Backscatter communication - This technique is essentially recycling existing radio frequency signals and reflecting them for communication to other devices. The devices that onboard this technique are low-powered or battery-less IoT devices, meaning they do not have to generate the radio signals themselves. Therefore, when considering billions of devices, it becomes apparent in its usefulness.

Dynamic Network Slicing - Partitioning the network virtually allows using a physical resource segmented among different users. This is achieved through SDN creating virtual networks for each use case, with the benefits of 6G regarding sensors and automation, dynamic allocation of resources can be leveraged to ensure further efficiency.

V. Software Defined Networks and Network Functions Virtualization

SDN and NFV are both technologies to which aim to provide more efficient, flexible and cost-effective networking results. Dynamic networking is a requirement for 6G to operate at full capacity creating self-optimising networks. With exceptionally fast data speeds, optimization is key in maintaining stability across all facets that deploy 6G networks. Network slicing is allowing for SDN to allocate resources based on use case (e.g. sensors, health centre, automated transport) appropriately. Combing AI/ML, complex but quick decisions can be made to ensure stabilisation throughout the network.

Shifts towards software and virtualized solutions results in a shift away from hardware dependency. Without constraints with hardware deployment and maintenance, scalability and efficiency is far greater. Self-optimising networks and rapid deployment of virtual machines through NFV, achieves what 6Gs high capacity is proposed to be.

VI. Analysis of 6G's Future

The future of 6G envisions a connected world where digit world and physical world begins to overlap more than ever. The proposed improvements such as increase to terabit data rates, latency of one millisecond and AI integration. By which bring forth networks capable of sustained holographic communication, brain-computer interfaces and enhanced virtual reality [2][3][10].

The opportunity for enormous advances driven by the enabled technology of 6G leads a path for extreme optimization throughout all industries. The path would also pave transformations in networks for people and cities. The research into WIET and backscatter communication also puts 6G in scope for environmental concern with a positive involvement to some extent.

Although 6G is not exempt from concern and it has its limitations. It may result in a similar situation to 5G, where the promised expectations do not meet results. A major limitation for 5G in deployment was infrastructure, which brings concerns for 6G deployment. Because 6G is in development there is no indication of how it will perform. Evaluation of previous generation 5G, authors in [9] found that with 5G connections did not boast the same expected quality. Which is due to multiple handovers between base stations and 5G to 4G exchange, that is 5G being implemented on 4G architecture. Security a major factor in current networks, and security is ensured through private key encryption schemes such as RSA. However, with increasing research in quantum computing the is a possibility of quantum computers implementing Shor's algorithm, which provides an efficient method of brute forcing RSA encryption keys [12]. The National Institute of Standards and Technology (NIST) has proposed four QRC algorithms [13], however in [12], problems with integrating QRCs into current infrastructure proves difficult for many reasons. Therefore, for 6G, it enhances issues regarding infrastructure integration.

Estimated arrival of 6G is 2030s and expected coverage of 80% with 5G is 2028, there may have be challenges that need to be identified and address. The overall expectation of 6G exceeds 5G promises greatly, and it's determined that infrastructure is one of the most important factors in deployment. Without it, 6Gs revolutionary vision is only a fraction of its potential.

VII. Conclusion

A look back at each previous generation of cellular networks shows how each subsequent generation builds on top of the previous and enhances the capabilities. The technological advances in the previous 20 years have seen great improvements to accessing the internet. Although 5G fell short relative to expected results and with 6G on the horizon it is fair to question the promises of 6G.

5Gs introductions shortcoming was due to the lack of infrastructure to support it in the use case of everyday users. Industry and infrastructure benefited from 5G with IoT devices and sensors. 6Gs vision looks to greatly benefit both everyday users and industries, however the underlying infrastructure dictates how far it can be taken.

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